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AN ANALYSIS OF THE SKIPPING CHARACTERISTICS

OF SOME FULL-SIZE FLYING BOATS

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SUMMARY

An analysis is made of the skipping characteristics of some full-size flying boats. In many cases the only source of data was pilot opinion, and sometimes this was contradictory. It was found that the more experience a pilot had with a particular airplane, the more apt he was to be untroubled by the skipping characteristics of that airplane.

Since it is currently desirable to design for inexperienced pilots, a figure of merit was adopted which is in inverse proportion to the amount of experience required to make stable landings. Using this basis for analysis, it has been found that the skipping characteristics can be improved by

1. Decreasing the initial load coefficient

2. Increasing the step height

3. Decreasing the sternpost angle

The load coefficient and the sternpost angle will ordinarily be chosen from other considerations. Figure 4 may then be used to determine a step height which should insure freedom from good skipping.

There are other unresolved hull form parameters which are known from model tests to have large secondary effects on skipping. Hence, use of the dashed line in figure 4 may be considered as an upper limit for purposes of good design.

INTRODUCTION

Skipping may be defined as an unstable oscillation of hydrodynamic

origin, predominantly heaving in character, which can occur just after landing or just prior to take-off. Skipping is associated with conditions whereby the forebody carries most of the water-borne load and at the same time a large amount of water is washing over the afterbody bottom. A good description of the mechanism of skipping may be found in reference 1.

Too numerous a series of serious accidents to both large and small flying boats has been traced to skipping. Because of the fact that hulls with quite violent skipping tendencies can be safely handled by experienced and careful pilots, there has been, in the past, some tendency on the part of designers to minimize the inherent danger. The accumulated experience of the average pilot is decreasing during the war; furthermore, there is tactical need for operations under increasingly adverse conditions. New airplanes should be designed, therefore, to take into account these two factors which have an important effect on the landing characteristics of a long-range military flying boat. Not only may the pilot be relatively inexperienced, but he also may be fatigued or wounded. Further, because of lack of fuel at the end of a long flight, it may be necessary to set down in rough water. Hence, it would seem to be very important for new military flying boats to have especially good landing characteristics under adverse conditions.

The purpose of this report is to gather together in one place information on the skipping characteristics of a number of flying boats. A graph showing the influence of the hull form on the skipping characteristics is given which should be useful in laying out the proportions of the hull in preliminary design to insure good landing behavior. Upper-limit porpoising is not considered in this report.

DATA

In tables I and II, the pertinent particulars and specifications, and a single word describing the skipping characteristics are given for each hull. In some cases, this one word represents an interpretation of a flight-test report, and in others the interpretation of opinions expressed by different pilots who had flown the particular airplane. In a few cases, diammetrically opposed views were obtained from different pilots. The viewpoint appears to be in function of the amount of experience tho dissenting pilot has had with the airplane. A good example is the Catalina, about which one pilot said: "It can be landed under any circumstance without skipping." He had had a great deal of experience with them. Another pilot, who had a great deal of experience with Mariners, said: "I have the 'willies' whenever I have to land a Catalina." Actually, neither pilot is entirely wrong. The first man was able to make stable landings instinctively by virtue of experience

which the latter pilot did not have. A third pilot, who liked the Catalina, stated he could land it without skipping any time he wished, but that it would skip very unpleasantly when landed improperly. This man had more experience with different types of flying boats than either of the other two. It seemed proper, then, to rate the skipping characteristics of this flying boat as only "fair."

Similarly, the other hulls are rated as "good" when, under most circumstances, they could make stable landings. The "poor" hulls are those which, in most cases, are unstable on landing. In nearly all cases, both stable and unstable landings are possible depending on pilot technique. The method of rating, therefore, is to some degree the inverse of the amount of pilot experience required to make stable landings.

The behavior on landing was chosen as the criterion of comparison because, on the basis of experience, it seems to be somewhat easier to induce skipping accidentally on landing than on take-off. Any flying boat that showed any evidence of inadvertent skipping on take-off, therefore, was automatically rated as poor.

The data are not really quantitative. A method of making the results quantitative would be to determine the range of stable and unstable landing trims for all the hulls listed. This should enable a much better correlation of skipping with hull form. An appendix gives such detailed information as could be found about each flying boat. It is not believed to be sufficiently complete to improve materially the interpretation of the data.

Throughout this report the following notation and nondimensional coefficients are used:

C_{Δ_0} initial load coefficient

L_f/b forebody length coefficient

L_a/b afterbody length coefficient

h   step height

σ sternpost angle

where

Δ_0 initial load on the water, pounds

w   specific weight of water, pounds per cubic foot (64.0 for sea water)

b   beam at main step, feet

L_f forebody length, measured from the intersection of chine and keel
           to the step centroid along a line parallel to the tangent to
           the forebody keel, feet

L_a afterbody length, measured from the step centroid to the second
           step or sternpost along a line parallel to the tangent to the
           forebody keel, feet

h   step height, measured at the step centroid, percent of beam at
           step

σ sternpost angle, the angle between the tangent to the forebody
           keel at the main step and a line joining the tip of the step
           and the sternpost, degrees

Figure 2 defines the principal dimensions used. Considerable effort
has been made to bring the dimensions, given on tables I and II, into
conformation with these definitions. Unfortunately, errors may still
exist because it was found on several occasions the drawings of the same
airplane issued by the same manufacturer would be inconsistent. How-
ever, it is believed that the dimensions given here are a good deal
more accurate than those given in reference 2 and at least as accurate
as, if not more so than, those given in reference 3.

ANALYSIS

At the outset, it appeared that the get-away speed coefficient
might be the primary independent variable (reference 1). However, it
does not make a very satisfactory variable for correlating full-scale
behavior because it depends on extraneous things like flap setting, wind,
and pilot technique. Wing loading would eliminate these things, but it
has the important disadvantage that it is not clearly related to the hull.
On the other hand, the initial load coefficient C_{Δ_0} is a more suitable
variable since empirically it is a function of the get-away speed. (See
reference 2.) It varies when the hull size is varied with a given wing
and gross weight, or when the gross weight changes in a given airplane.
Hence, C_{Δ_0} has been used as the primary independent variable. For
studies of systematic model experiments it would not be nearly so satis-
factory as it is here.

The first step taken was to plot the step height h against the
initial load coefficient C_{Δ_0}. The result is shown in figure 3, where

the different skipping behaviors are differentiated by different symbols.
A line which has been cross-hatched on the undesirable side was drawn to
put a few "good" points below and as few "fair" or "poor" points above
the line as possible. It is evident that this line is not very effec-
tive in "separating the sheep from the goats." The next step was to
plot σ against C_{Δ_o} in various ways. Figure 4 shows that by using·
h/σ some improvement is achieved over the correlation shown in figure
3.

Further plots, which introduced afterbody length and get-away
speed coefficient in various fashions as additional parameters, were
tried; these indicated no systematic effect of either variable. Since
a fairly good correlation had already been obtained in figure 4, the
matter was not pursued further.

   DISCUSSION

The limitations of the data should be kept firmly in mind. It is
more or less quantitative, being, as far as possible, the average of
more than one opinion. It cannot, however, be very precise by its very
nature. Even with the hulls classed as "poor," stable landings in the
hands of a capable and experienced pilot are possible. Thus, it is
difficult to lay down a hard-and-fast line, differentiating between the
hulls having "good" and "poor" skipping characteristics. This is espe-
cially true since there are known to be secondary variables of consid-
erable importance. It is believed, however, that the dashed line in
figure 4 should provide a safe basis for preliminary design.

Figure 3 merely reaffirms all previous experience (references 1, 3,
4, and 5) that the step height has a powerful influence on the skipping
characteristics. It seems clear, however, that there has not been suf-
ficient delineation of the "poor" from the "good" hulls to allow using
this chart for design purposes. A dashed line was drawn in parallel to
the cross-hatched line so that the XPBB-1 point lay above the line,
because this flying boat has outstandingly good skipping characteristics.
The line serves to emphasize the necessity of deep steps.

Figure 4 shows a quite good correlation of skipping characteristics
with hull form. It indicates that, if the sternpost angle is fixed from
other considerations, then the step height for good skipping character-
istics may be found, and that the higher the sternpost angle the higher
the step height must be to give desirable skipping characteristics. At
first glance, this is surprising in view of Parkinson's "jet" conception
(reference 1) from which it might be expected that, with a fixed step
height, skipping would be reduced by increasing the sternpost angle in-

stead of harming it. However, model tests (reference 6) actually indi-
cate that the skipping characteristics are somewhat harmed by increasing
the sternpost angle. Since Parkinson's theory gives such a reasonable
explanation of step height and ventilation, it is thought that the in-
fluence of the sternpost angle must be largely confined to the rear half
of the afterbody.

The explanation may lie in the following schematic sketch, which is
intended to show the independent effect of both sternpost angle and step
height on the stability limits.
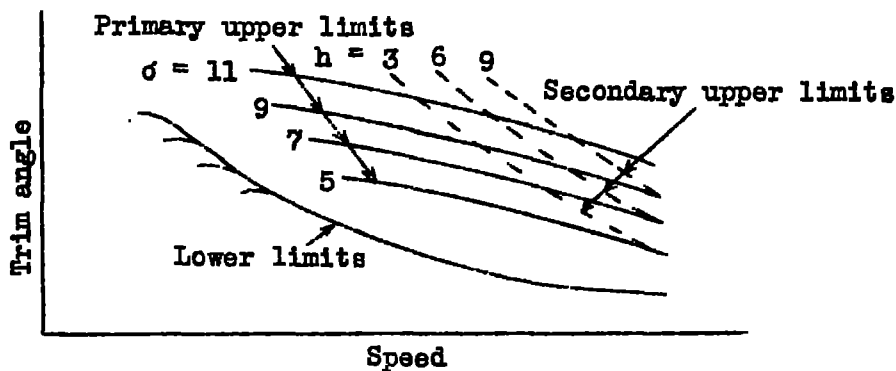
Model data in reference 5 indicates that the primary upper limit
is unaltered by changes of step height alone. On the other hand, model
data in reference 6 shows that the variations of the sternpost angle
cause only relatively small changes in the position of the secondary
upper limit. There is apparently a region of speeds and trims in which
skipping is possible with a given step height and moderately large
afterbody angle. As the sternpost angle is reduced, the primary upper
limit covers up more and more of this region, until a point is reached
below which no further improvement in the skipping characteristics
should be expected. Hence, the preceding sketch may be taken as at
least an indication of the combined influences of step height and
sternpost angle, and is an extension of similar sketch in reference 7.
It does not seem unreasonable to push the ideas expressed in reference
7 a little further and state that the rear half of the afterbody is
largely responsible for the primary upper limit, and the forward half
for the secondary upper limit, and skipping characteristics. This con-
ception is probably a valid explanation of figure 4. It is believed
that this brings about only a clarification of the ideas expressed in
references 1 and 3, and that Parkinson's "jet" theory offers a broad
explanation of the mechanism of skipping.

The sternpost angle ordinarily will be chosen to give as high a
primary upper limit of stability as is compatible with hump trim angles
and main spray characteristics. The step height which should ensure

good skipping characteristics can then be found with the aid of the recommended line in figure 4. The step height found in this manner will be a great deal deeper than has been ordinarily used in past practice. It will, unfortunately, cause a considerable amount of air drag. By keeping in mind Parkinson's jet theory, which requires that air be admitted to relieve the low pressures created by the high-speed jet issuing from the step, there appear to be several ways of reducing the step height while retaining good skipping characteristics.

The first method is by using a step of moderate depth and ventilation ducts running into the afterbody bottom. The area of the required ducts is quite large (reference 1) and they may interfere seriously with the interior arrangements of the flying boat. Ventilation ducts have been used on several aircraft which already had poor skipping characteristics; when sufficient duct area was used, they seemed to have a beneficial effect on the skipping characteristics.

A better method of reducing the necessary step height is to use a V-plan-form step (reference 8). As may be seen from table I, the V-plan-form step has been quite widely used in the past. If an ordinary transverse step is transformed into a V-step, as on the PBN-1, the change may accomplish very little. On the other hand, if the hull is designed for a V-step, as on the Short "Empire," and if it is not too shallow, the V-step can be superior to the ordinary transverse step. To illustrate the differences in the V-steps of these two airplanes, the sketches in figure 1 are worth noting. On the "Empire" boat, the face of the V-step is of uniform depth, while on the PBN-1 there is a definite throttle near the chine. Model and full-scale experiments on ventilation (references 1 and 9) have shown that the introduction of air at the keel is needed to alleviate skipping. From an examination of the PBN-1, because of the throttle near the chine, it seems obvious that air would have a great deal of difficulty reaching the keel.

Since the V-step is believed to be fundamentally superior to the transverse step, an opportunity arises for aerodynamic fairing. British tests (references 3 and 10) on the Sunderland III have indicated that by using a moderate fairing the water stability is not appreciably altered. It is also reported that such a fairing increases the cruising speed about 5 miles per hour, which is an exceedingly large benefit.

Afterbody length, step plan form, and the difference between the forebody and afterbody dead rise near the step undoubtedly influence the skipping characteristics. It is not easy to disentangle their separate influences from the available full-scale data. Reference 3 should be consulted for a summary of model and full-scale evidence on these and other points. It would appear that the only satisfactory method of determining the individual effect of other hull-form variables is through systematic model tests.

One of the things which keeps recurring in the British reports concerning skipping (references 9, 11, and 12, for instance) is that disturbed water aggravated the skipping very materially. The Sea Otter (reference 9) is apparently stable during take-off, but violent skipping was set up when it ran across the wake of a boat. Reference 4 recounts some of the model experience at Stevens Institute of Technology on the influence of rough water on skipping. In another case a model that seemed quite stable could be induced into a violent self-sustaining skipping by allowing it to run through three of four waves. These experiences serve to emphasize the necessity of exceptionally good skipping characteristics, so that rough-water landings can be performed safely.

CONCLUSIONS

On the basis of available full-scale evidence bearing on the skipping characteristics of flying boats, step height, sternpost angle and load coefficient appear to be the major variables.

The sternpost angle should be selected so as to obtain the best compromise involving the primary upper limit of stability, hump trim angles, and the main spray characteristics. When the sternpost angle has been selected, the step height may be found by using the dashed line on figure 4.

The shape and location of the rear half of the afterbody control the location of primary upper limit. The shape and location of the forward half of the afterbody control the location of the secondary upper limit and the skipping characteristics. These two bald statements are believed to be in substantial agreement with the conceptions expressed in references 1 and 3.

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APPENDIX A

DETAILS OF THE SKIPPING CHARACTERISTICS OF VARIOUS FLYING BOATS

This appendix gives more information on the skipping characteristics of the various flying boats listed in tables I and II. The purpose of this greater detail is primarily to justify the "merit" in which each hull was classed. It also should be useful in that it gathers together in one place available information on the various hulls. More information on the dimensions of some of the airplanes may be found with the aid of reference 2.

Amphibians P-III-B   Poor

The following is quoted from a hydrodynamic data report by C. E. Kahlka, Jr., in 1942: "It was usually possible to check oscillations during the high-speed portion of the run before they acquired appreciable amplitude, but at times this was decidedly tricky and involved skipping over the water surface much like a skipping stone."

Grumman J4F-2   Good

As far as could be determined, no trouble has been experienced with skipping. The airplane apparently has a tendency to nose over when landed at too low a trim angle, but this is more likely to be connected with the low dead-rise bow sections and convex curved water planes of the forebody, than with the skipping characteristics.

Vought OS2U-1   Good

This airplane has a considerable amount of lower-limit porpoising during take-off unless skillfully handled. No reports of skipping on landing have been found, however.

Saro 37   .   Good   ] References 3 and 11

Fairly complete tests indicated some danger of skipping if the pilot allowed the airplane to get into abnormal attitudes. The worst condition appeared to be the full-stall landing; otherwise landings were stable. Rough water aggravates matters.

Fairey Seal   Poor   Reference 3

    This twin-float seaplane apparently has no stable range or else a very narrow one. Conditions are worse in rough water than in smooth.

Grumman J2F-5   Fair

    According to pilot's opinions, full-stall and flat-power-on landings are stable, but there is a rather wide range of intermediate angles which are unstable.

Curtiss XSC-1   Good

    Preliminary reports indicate good landing characteristics.

Grumman JRF-4   Fair   Reference 1

    Full-stall landings are quite stable, and intermediate angles moderately unstable. Fast, flat, power-on landings are very unstable. The landing stability of this aircraft has been considerably improved by moving the step aft, thereby increasing the step height. Landings over quite a wide range of trims are now stable. The altered aircraft is called the JRF-5.

Supermarine Sea Otter   Poor   Reference 9

    A little rough water would set up violent skipping during take-off. Structural damage to the engine mount was experienced after skipping during one landing.

Hall PH-3   Good

    Full-stall and moderate angle landings quite stable according to one pilot. This may well be partially attributable to the very low wing loading.

Consolidated PBY-5   Fair

    Full-stall and flat power-on landings are stable, but there is a rather wide range intermediate angle which is moderately unstable.

<u>Naval Aircraft Factory PBN-1</u> <u>Fair</u>

  Landings made at low trims are quite stable, but some skipping encountered at higher trims. Full stall is unstable. Ventilation, using 1.7 square feet of ventilation area, helped a little. There is disagreement as to whether this airplane is better or worse than the PBY, from which it was derived.

<u>Short Singapore IIc and III</u> <u>Good</u> <u>Reference 3</u>

  Behavior quite similar to the Hall PH-3, of which the Singapore is a contemporary. The stable range of trims for this hull is about 8° wide.

<u>Saro Lerwick</u>   <u>Reference 18</u>

  According to reference 18, the shallow transverse step was exceeding unstable full-scale; after lowering the forebody and incorporating a V-step, a full-scale stable form was produced. The modified hull has almost 11 percent step depth at the keel. The results shown in reference 3 are believed to apply to the original form.

<u>Short Sunderland I</u> <u>Good</u> <u>Reference 14</u>

  The airplane has a wide range of attitudes for stable landings. From about 4° to 9° trim angles are stable.

<u>Consolidated 31</u> <u>Poor</u>

  Consolidated flight tests indicated skipping during both take-off and landing.

<u>Consolidated XP4Y-1</u> <u>Fair</u>

  Consolidated flight tests indicated a very marked improvement, though apparently there was still some skipping on landing.

<u>Martin PBM-3</u> <u>Good</u>

  It is possible to land this aircraft over a wide range of trims without any difficulty from skipping.

Short Sunderland III   Good   Reference 10

Even with a 1:4 step fairing, deliberate attempts to get skipping
were quite unsuccessful. In reference 10, it is stated that by making
violent full-stall landings an occasional skip would be encountered, but
not enough to define a stability limit. Service usage has indicated
that the full-stall landing is unstable in slightly rough water. How-
ever, a fairly large number of the aircraft have been in service for
about four years, and by landing at intermediate angles have had no
trouble from skipping.

Martin PBM-5   Fair

The aircraft has been considerably overloaded. Mild skipping can
be found between trim angles of 10° and 14°. The intensity of this
skipping increases with increasing gross weight.

Boeing XPBB-1   Good   Reference 1

It is possible to get upper-limit porpoising with this flying
boat, but, as far as is known, there is no skipping on landing at any
attitude or load. It is looked upon with great enthusiasm, as far as
skipping is concerned, by all pilots who have flown it. It is believed
to be the most stable aircraft in service today.

Consolidated PB2Y-3   Poor   Reference 1

Violent skipping was found over a wide range of trims. After pro-
duction had started, the skipping was alleviated by the introduction of
ventilation ducts. Some pilots have stated, under controlled test con-
ditions, that they could not tell from the instability on landing whether
the ducts were open or closed. Other pilots have reported considerable
improvement due to the step ventilation.

Short G   Fair   References 3 and 16

At low attitudes no instability occurs on landing, but, as the
trim increases, skipping is progressively introduced until, at high
attitudes, it is quite bad. According to reference 15 no trouble need
be had if the airplane is landed fast with a little power.

Boeing 314   . .   Reference 1
‾‾‾‾‾‾‾‾‾‾   ‾‾‾‾‾‾‾‾‾‾‾

    The flying boat was violently unstable just after landing at high
trims. By moving the step aft, thereby increasing the depth because of
the angle between the forebody and afterbody keels, a great improvement ·
in landing at high trims resulted.

Martin XPB2M-1   Fair   · ·
‾‾‾‾‾‾‾‾‾‾‾‾‾   ‾‾‾‾

    At trim angles below about $6°$ this airplane is stable. Above this
trim, quite violent skipping can be obtained. Because of the large
size of the airplane, the motion is quite slow and is very easy to con-
trol and, hence, may not be objectionable to the pilot. However, it
should be noted that a large number of the pilots have been men with
years of flying-boat experience. Model experience with this airplane
(reference 3) indicates that it is not so good as it could be with a
deeper step.

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TABLE I.- SKIPPING CHARACTERISTICS OF VARIOUS FLYING BOATS

| Manufacturer	Model	Gross weight (lb)	Wing area (ft²)	Beam (ft)	C_{Δ_o}	Step		$\dfrac{L_f}{b}$	$\dfrac{L_a}{b}$
						Height percent b	Shape [1]		
Amphibians	P-IIIB	3,200	224	4.66	0.493	4.5	T	2.05	1.92
Grumman	J4F-2	4,500	245	4.25	.915	6.6	T	3.13	2.12
Vought	OS2U-1	4,841	261	3.67	1.530	7.8	T	3.85	3.08
Saro	37	5,700	340	4.25	1.160	10.0	20°FV	3.60	3.73
Fairey	Seal	6,400	445	3.20	1.525	6.5	T	4.22	3.37
Grumman	J2F-5	6,651	409	5.00	.830	5.0	T	2.86	2.69
Curtiss	XSC-1	7,642	281	4.38	1.420	8.8	T	3.64	3.04
Grumman	JRF-4	8,000	375	5.00	1.000	5.9	T	2.84	2.33
Grumman	JRF-5	8,000	375	5.00	1.000	7.3	T	2.93	2.24
Supermarine	Sea Otter	10,200	610	5.17	1.153	4.0	T	3.20	3.90
Hall	PH-3	16,150	1170	8.35	.435	3.35	T	2.90	1.69
Consolidated	PBY-5	26,000	1400	10.21	.380	3.5	T	2.44	1.51
Short	Singapore II	26,600	1760	10.70	.339	4.6	30°V	2.32	2.16
NAF	PBN-1	28,000	1400	10.19	.415	3.5	20°V	2.70	1.94
Short	Singapore III	31,150	1760	10.70	.397	4.6	30°V	2.32	2.16
Saro	Lerwick Ia	33,000	845	8.48	.845	3.4	T	3.04	3.69
Saro	Lerwick Ib	33,000	845	8.48	.845	7.2	30°V	3.16	3.57
Short	Sunderland I	43,000	1487	9.10	.892	9.7	30°V	3.47	3.36
Consolidated	31	46,000	1048	9.17	.930	2.4	T	3.01	2.51
Consolidated	XP4Y-1	46,000	1048	9.17	.930	4.9	30°V	2.94	2.58
Martin	PBM-3	46,500	1406	10.00	.725	5.0	T	3.28	2.74
Short	Sunderland III	50,000	1487	9.10	1.035	9.7	30°FV	3.47	3.36
Martin	PBM-5	56,000	1406	10.00	.873	5.0	T	3.28	2.74
Boeing	XPBB-1	62,000	1826	10.42	.855	9.0	T	3.40	2.67
Consolidated	PB2Y-3	68,500	1780	10.50	.925	3.5	30°V	2.85	2.14
Short	G	73,500	2390	11.65	.726	5.7	30°V	3.10	3.45
Boeing	314	82,500	2867	12.50	.660	3.0	T	3.60	2.12
Boeing	A-314	82,500	2867	12.50	.660	4.75	T	3.75	1.97
Martin	XPB2M-1R	140,000	3683	13.50	.890	5.0	T	3.32	2.75

[1] T - transverse step; V- V-step; FV - faired V-step.

TABLE II.- SKIPPING CHARACTERISTICS OF VARIOUS FLYING BOATS

Model	Dead rise[1]		Sternpost angle (deg)	Landing merit	Source
	Forebody (deg)	Afterbody (deg)			
P-IIIB	7	7	12.0	Poor	Owner's flight tests
J4F-2	20	20	7.0	Good	Opinions
OS2U-1	25	25	7.8	Good	Opinions
37	27	37	9.0	Good	RAF flight tests
Seal	37	37	7.6	Poor	RAF flight tests
J2F-5	25	25	9.0	Fair	Opinions
XSC-1	Fluted	Fluted	8.6	Good	Opinions
JRF-4	25	25	9.1	Fair	NACA RB No. 3127
JRF-5	25	25	9.5	Good	Opinions
Sea Otter	21	24	7.5	Poor	RN flight tests
PH-3	22.5	22.5	7.7	Good	Opinion
PBY-5	20	20	8.2	Fair	Opinions and RAF flight tests
Singapore II	26	30.5	8.6	Good	RAF flight tests
PBN-1	22.5	22.5	8.4	Fair	NAF flight tests
Singapore III	26	30.5	8.6	Good	RAF flight tests
Lerwick Ia	30	33.5	7.3	Poor	RAF flight tests
Lerwick Ib	30	33.5	8.0	Good	RAF flight tests
Sunderland I	31	41	9.4	Good	RAF flight tests
31	20	20	6.7	Poor	Consolidated flight tests
XP4Y-1	20	20	8.0	Fair	Consolidated flight tests
PBM-3	20	30	8.5	Good	Martin and NACA flight tests and opinions
Sunderland III	31	41	8.8	Good	RAF flight tests
PBM-5	20	30	8.5	Fair	Opinions
XPBB-1	20	20	7.6	Good	Navy flight tests and NACA RB No. 3127
PB2Y-3	22.5	22.5	·7.5	Poor	Consolidated, Navy, and RAF flight tests
G	31	41	9.5	Fair	RAF flight tests
314	22.5	22.5	6.9	Poor	NACA RB No. 3127
A-314	22.5	22.5	7.6	Fair	NACA RB No. 3127
XPB2M-1R	20	20	8.0	Fair	Navy flight tests and opinions

[1]Measured at step on forebody and at maximum dead rise on afterbody
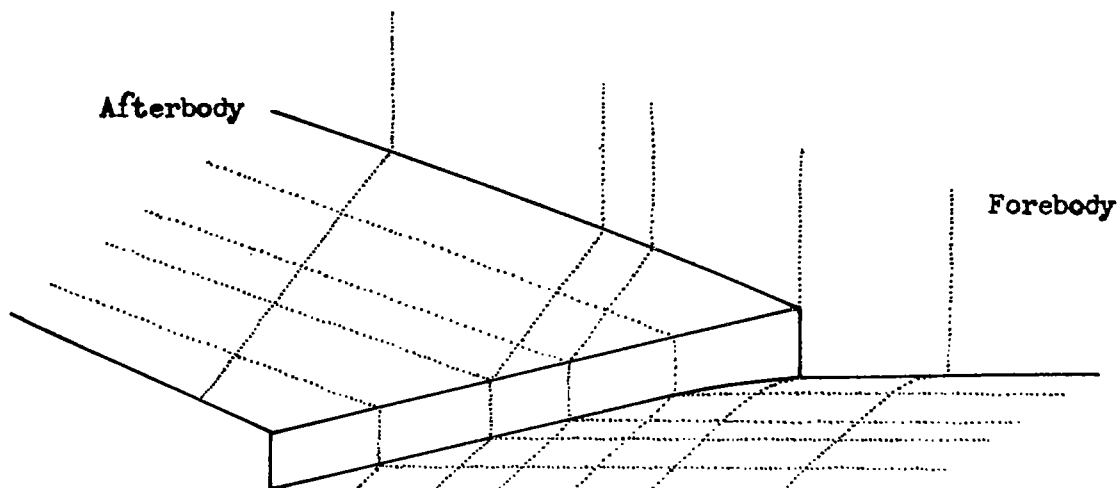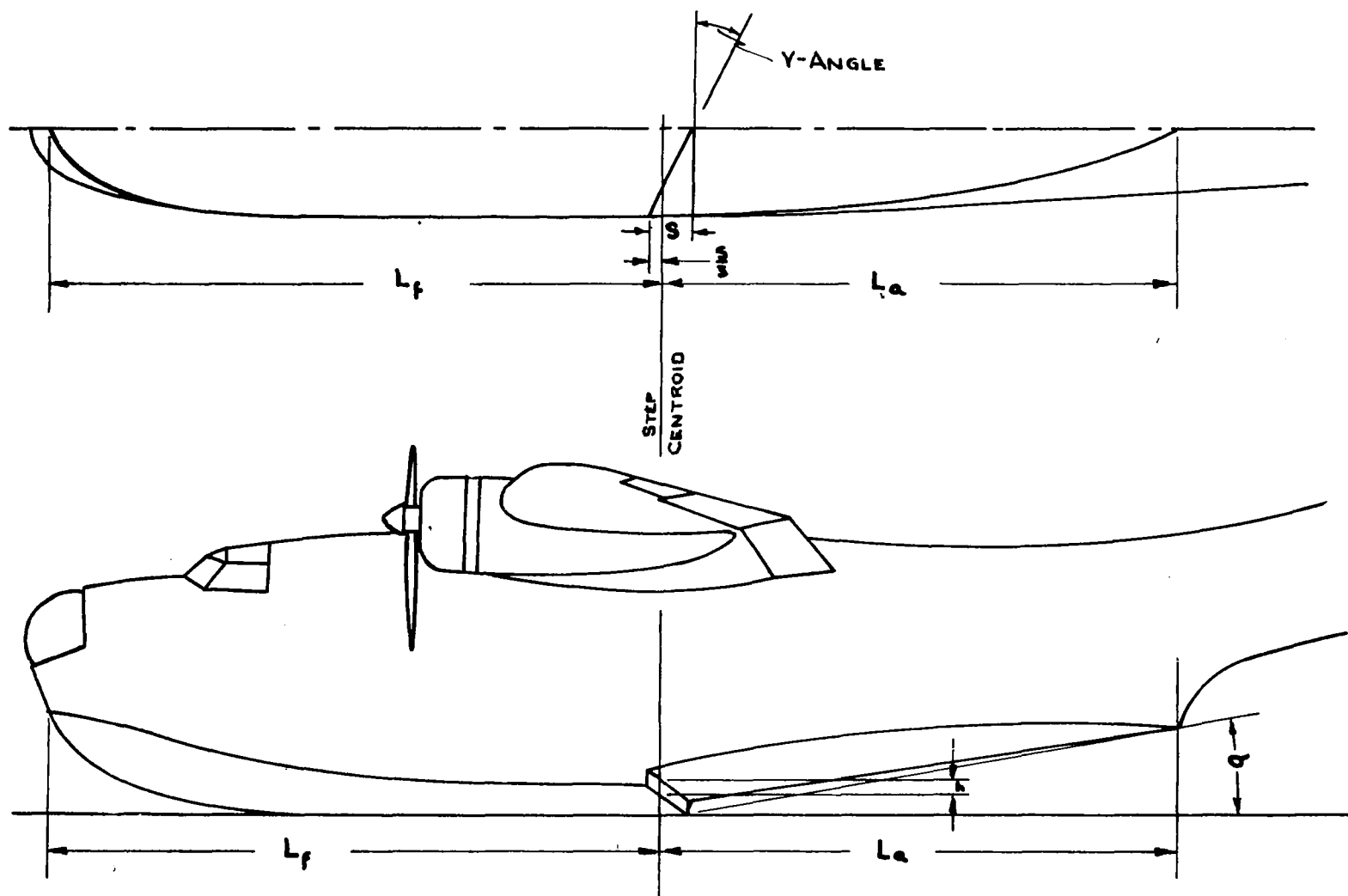
V-STEP USED ON THE SHORT "EMPIRE"

Note the uniform depth of the face of the step obtained by using greater deadrise on the afterbody than on the forebody.
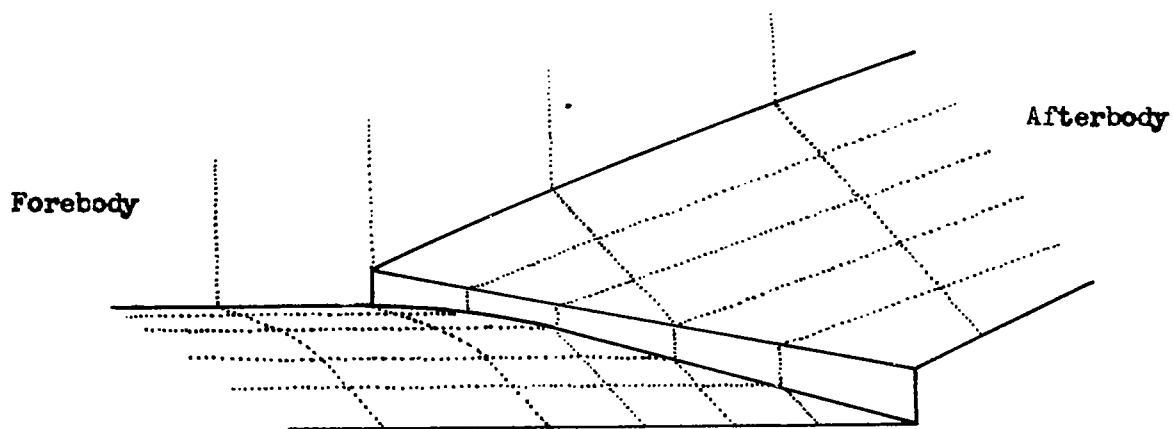
V-STEP USED ON THE PBN-1

Note the throttle in the step face resulting from using the same deadrise on the afterbody and forebody.

FIG. 1

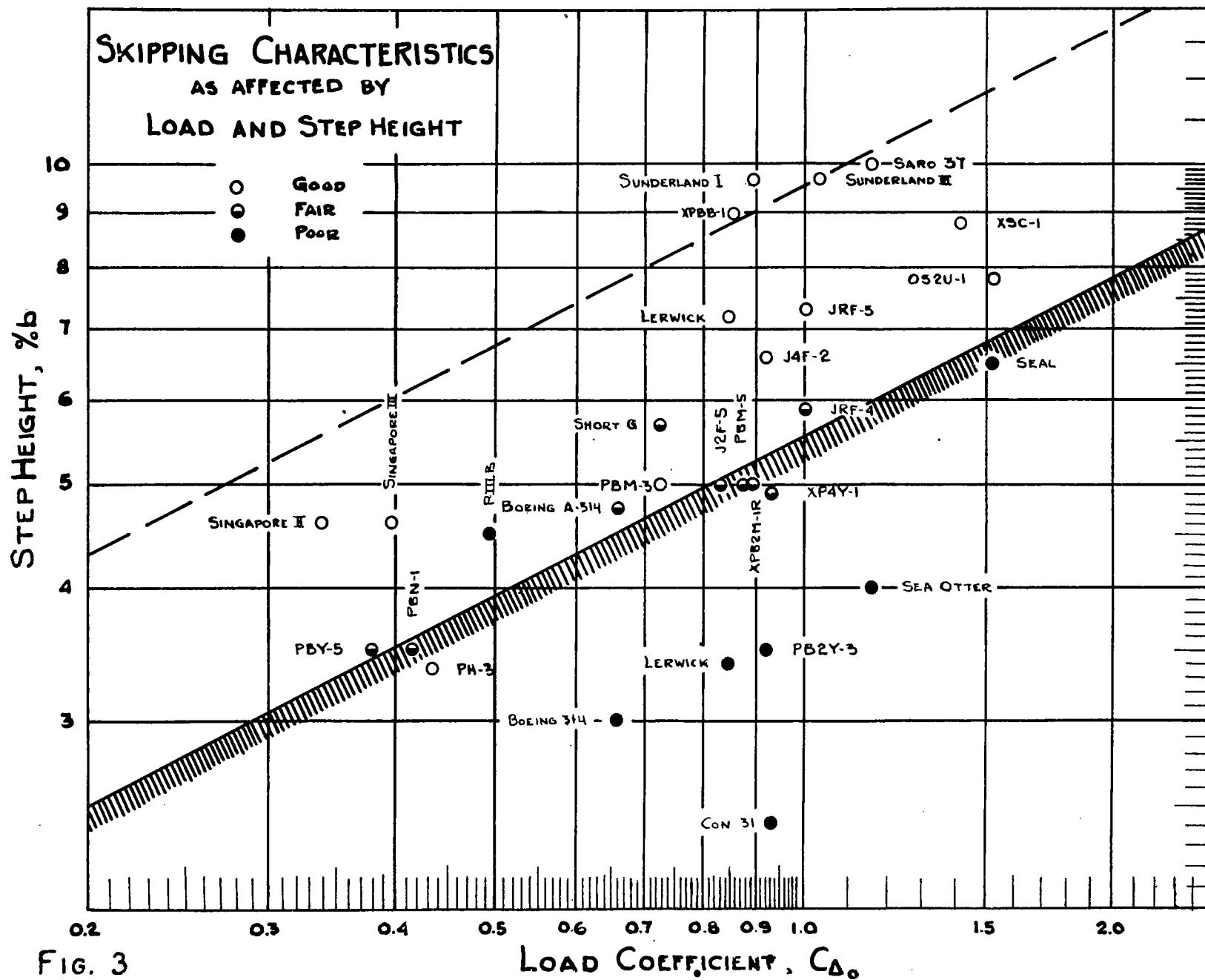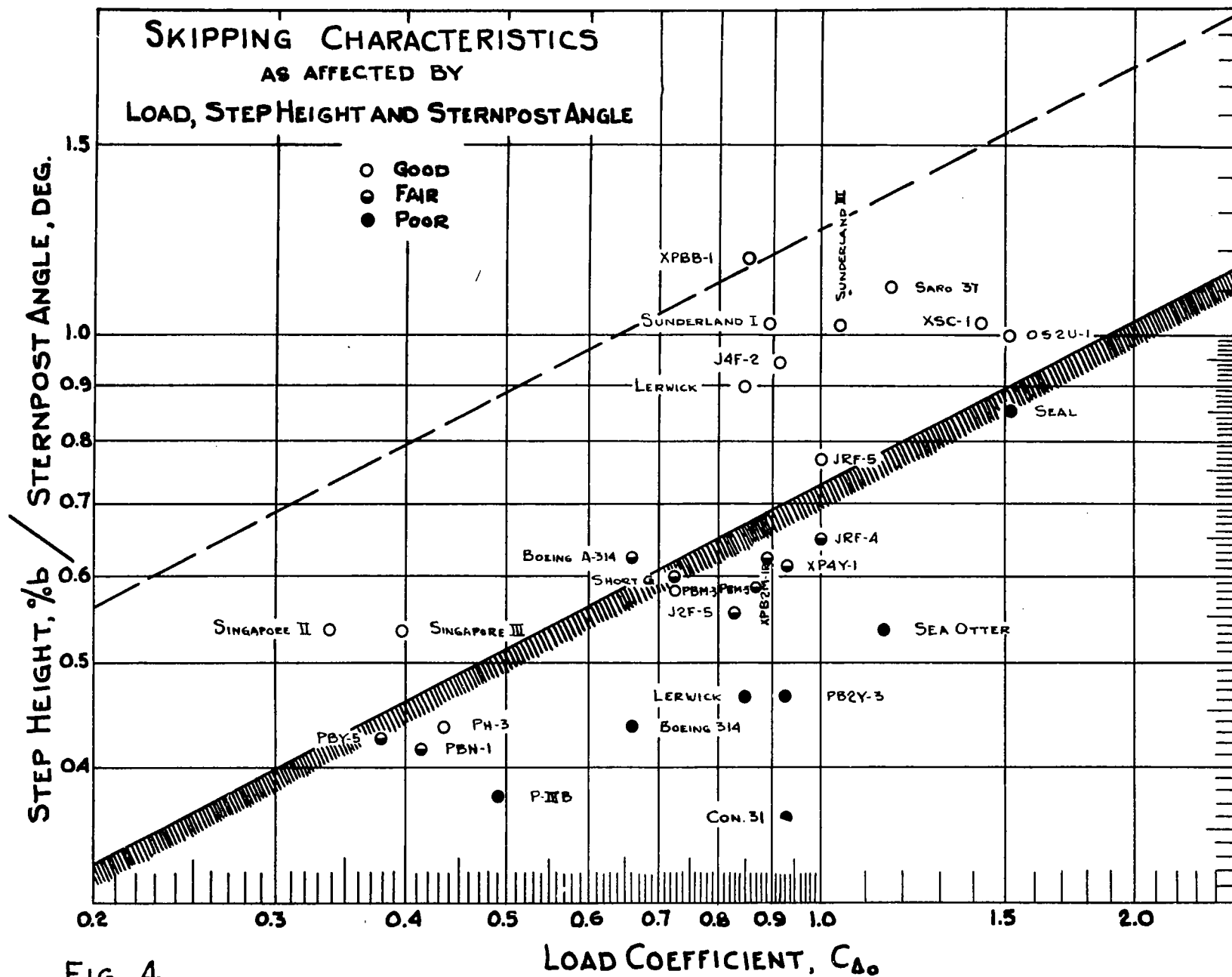SCHEMATIC SKETCH TO ILLUSTRATE
DEFINITIONS OF DIMENSIONS

FIG. 2

Fig. 2

Fig. 3 — Skipping Characteristics as Affected by Load and Step Height

FIG. 4